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Suitability of Compact Yarn for Manufacturing of Eco-Friendly Processed Weft Knitted Fabrics

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ABSTRACT

The investigation of physical characteristics of compact yarn weft knitted fabrics after treatment with enzymatic scouring, bleaching and natural dyed with Acacia catechu have been studied and compared with ring yarn weft knitted fabrics. In this research work the physical characteristics such as weight loss (%) in abrasion, pilling resistance, air permeability, fabric tightness factor, loop shape factor, wickability, bursting strength, spirality and dimensional stability have been studied with various knit structures and stitch length. From the test results, the spirality (%) of the Com4 and Sussen Elite spun yarn knitted fabrics had lower values when compared to ring spun yarn knitted fabrics. The higher weight loss (%) in abrasion was noticed in ring yarn knitted fabrics compared to compact yarn knitted fabric made out of Sussen Elite and Com4 spun yarns. The pilling resistance of these knitted fabrics has been observed higher in case of 2.7 mm stitch length compared to 3.3 mm stitch length, because of the higher fibre content and probability to form fuzzing on the surface of the fabric. The compact spun yarn knitted fabrics in all the knit structures were noticed lower dimensional shrinkage and also noticed that the aerial shrinkage of the knitted fabrics mainly depends on the stitch length, loop shape factor and tightness factor of the fabrics. The significant differences of the physical characteristics of these knitted fabrics were analyzed using ANOVA multivariable data analysis. This research study will be helpful for particularly knitwear industries and designer who are analyzing and dealing with compact spun yarn knitted fabric and garments through eco-friendly processes.

Keywords: Compact yarn, physical properties, enzymatic scouring, natural dyeing, spirality, dimensional stability

1. INTRODUCTION

A revolutionary version of the ring spinning process called compact spinning achieves remarkable improvement in yarn quality through better utilization of fiber properties which gives benefit in the downstream. Therefore, the fabric made from compact spun yarn gives better look and feel [1]. Compact yarns have a wide variety of opportunities to avail the special yarn properties in knitting. The most evident properties of these yarns are high breaking strength, high elongation and low hairiness [2]. The structure of the compact yarn offers many advantages in the downstream processing [3, 4]**.** The compact spinning produces a new yarn structure which approaches the ideal staple fiber yarn construction even more closely [5]. In the compact spinning, the fibers from the spinning triangle are collected and integrated in the yarn which result that the strength of compact yarn is improved by 15-20% and elongation by approximately 20% and hairiness is lowered by as much as 50% when compared with ring yarn [6]. Compact yarns are uniformly oriented and having better tenacity, elongation, and hairiness properties. The better tenacity properties of compact yarn provide opportunities to work with lower twist coefficients result in an increase in production rate and also better handling properties of the end product [7].

The carded ring and compact yarn plain knitted fabrics with three different loop lengths were made out of 20 Tex and then the fabrics were scoured and dyed, the test result shows that the knitted fabrics produced from compact yarns showed better pilling resistance and higher bursting strength when compared to the fabrics produced from regular ring spun yarns [8]. The performance assessment of ring and compact yarns in knitted fabrics with single jersey knit fabrics have been studied and reported that plain knitted fabric made out of compact spun yarn having better pilling resistance and abrasion resistance when compared to ring spun yarn knitted [9].

The wicking behavior of compact and ring spun yarns and their fabrics was studied and reported that the wicking height attained by compact yarns had greater than that of ring yarns and the equilibrium wicking height gained by them were also more. This has been attributed to the greater packing coefficient of compact yarns. The same trend was noticed in fabrics produced from compact yarns [10]. Creative solutions in woven and knitted fabrics have opened new segments and riches to the application of compact yarns. The condensed yarns in coarse, medium and relatively fine counts with new raw materials found increasing applications in the production of premium shirting and suiting fabrics, knit fabrics for inner wear, T-shirts, sweaters, sports wear ladies stockings, lingerie [11].

Knits being used for outer and innerwear included in all skin-contact end uses such as leg wear, footwear, lingerie, baby wear, sportswear, health care products and more recently home furnishings. The most revolutionary achievement of knitting is penetration into the formalwear segment [12]. The increased use of knitted fabrics for different classes of outerwear has placed greater demands on quality as well as appearance of knitted fabrics to meet the ever – changing fashion trends [13]. The comparison of cotton knitted fabric properties made of compact and conventional ring yarns before and after the printing process was studied and more uniform and high luster printing effect brought out in case of compact spun yarn fabrics [14]. Efforts are being made to make a knitted fabric more comfortable by changing the fibers, yarn parameters like twist, count and finishing treatments, knitting parameters like stitch length, course per inch, wales per inch and fabric weight and post knitting finishes [15]. Nowadays, the end use of compact yarn is becoming more and more important due to its special characteristics. Therefore, there is a need for assessing the quality of the knitted fabric produced from the compact yarn. In the case of weft knitting, the dimensional properties of stable weft knitted fabrics depend mainly on the average loop length. In an earlier work, many attempts were made by researchers to analyze the relationships among the dimensions of knitted fabrics, the properties of the constituent yarns and the variable factors in knitting. It was noticed that the dimensional and weight related properties of the knitted fabric in a relaxed state were determined uniquely by length of yarn in the stitch [16]. This research work was carried out to investigate the physical characteristics of knitted fabrics using ring and compact spun yarn on various knit structures such as single jersey, rib and interlock with different stitch length after treatment with enzymatic scouring, bleaching and natural dyeing with Acacia catechu.

2. MATERIALS AND METHODS

For this research work, the cotton yarn of 40s Ne count was selected from three spinning systems namely Ring spinning, Sussen Elite and Com4 spinning systems. The quality parameters of these yarns are given in Table 1. The yarn samples were tested for count, Lea strength and CSP using automatic wrap reel, Lea tester and Electronic balance. ASTM D1907 -01 for count and ASTM D1578-93 for yarn strength were followed. The yarn unevenness, imperfection were tested on USTER tester III as per ASTM D1425-96 test method at 400 metres/minute. The compact spun yarns of both Sussen Elite and Com4 are having better strength and higher friction co.efficient values when compared to ring spun yarn which is due to better integration of fibres into core yarn structure and uniform orientation of compact yarns.

TABLE 1. YARN PROPERTIES

Parameters	Ring spun yarn	Sussen Elite Compact spun yarn	Com4 Reiter Compact spun yarn
Nominal count, Ne	40	40	40
Actual count, Ne	39.3	39.5	39.1
Single yarn strength, grams	245.5	252.4	300.9
CV% of yarn strength	9.92	9.21	7.76
Elongation, %	5.55	5.43	4.53
CV% of yarn elongation to break	6.21	5.54	9.44
Co.efficient of yarn friction, μ	0.17	0.19	0.21
Unevenness, %	11.32	10.40	9.91
CV% of yarn	14.36	13.13	12.51
Imperfections / 100 km			
Thin places (-50%)	5	1	0
Thick places (+50%)	98	37	21
Neps (+200%)	226	46	39
Average twist per inch (TPI)	25.46	24.62	24.83
C.V% of twist per inch	2.32	1.68	1.42
Twist multiplier (TM)	4.10	3.90	3.90

2.1 KNITTING

Single jersey, rib, interlock knitted fabrics were made from Ring spun yarn, Sussen Elite, and Com4 yarns individually and combined with three different stitch length of 2.7mm, 3.0mm and 3.3mm respectively in all the fabric structures using regular knitting machines. The flow chart for fabrication and wet processing of this research work is given in Figure 1. The details of knitting process parameters are given in Table 2. After knitting, the fabric samples were dry relaxed and wet processed. Wet processing includes enzymatic scouring, bleaching and dyeing with natural dyes.

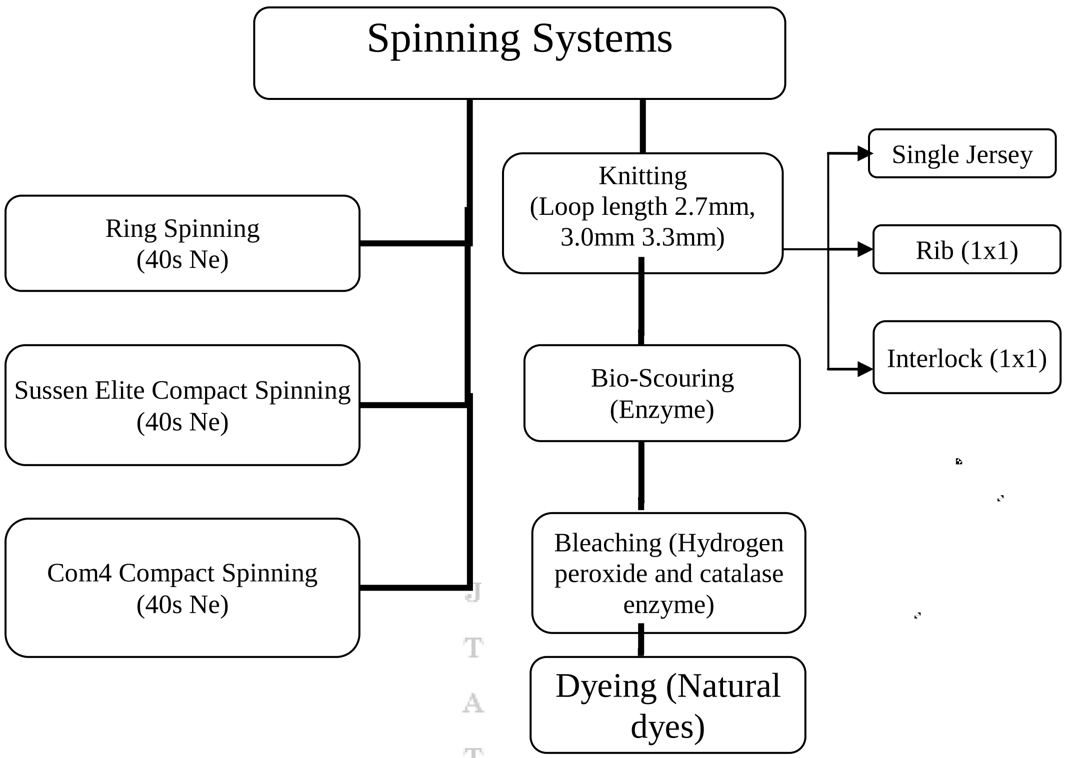

FIGURE 1. PROCESS FLOWCHART FOR FABRICATION AND WET PROCESSING OF KNITTED FABRICS

TABLE 2. KNITTING PROCESS PARAMETERS

MACHINE PARAMETERS	SINGLE JERSEY KNITTING	RIB KNITTING	INTERLOCK KNITTING
Machine make	LISKY (TAIWAN)	PAI LUNG (TAIWAN)	PAI LUNG (TAI WAN)
Machine model	LTK / 120 SJ-4	PL-SD 2.5 B/CE	PL-SD 3.9 B/CE
Gauge (Needles per inch)	24	18	24
Diameter, inches	26	26	26
No. of feeders	104	62	72
Machine speed, rpm	30	30	30
No. of needles	1954	1464	1961

2.2 ENZYMATIC SCOURING, BLEACHING, MORDANTING AND NATURAL DYEING

The enzymatic scouring was done in the bath with liquor ratio 1:20 with 2% enzyme concentration using laboratory model winch dyeing machine. The fabric was loaded into the bath at 20^0C and then the bath was heated to 50^0 to 65^0C for 60 min. The bleaching was done in the same bath. The bath was cooled to 60^0C and then added 5% H_2O_2, 5 g/l of sodium silicate as stabilizer. The bath was heated to 98^0C and the fabrics were bleached for 60 min. The scoured and bleached fabrics were rinsed at 80^0C 10min, twice at 60^0C 10 min and cold wash at room temperature 10 min, then the bleached fabrics were taken into neutralization with catalase enzymes treated with 2% concentration at 55^0C, 30min, then fabric was washed twice in hot water and cold water. The bleached cotton knitted fabrics both ring and compact spun yarns made were taken into natural dyeing process.

The bark and heart wood of *Acacia catechu* were collected from the munnar forest, dried and powdered using electric blender, and impurities were removed manually. The catechu powder (100g) refluxed with alcohol water (40:60) in a round bottom flask was fitted with air condenser at about 60-70ºC for 1-2 hours. The aliquot was decanted and fresh ethanol water was added and the above process was repeated 2-3 times for complete extraction. All the aliquots were transferred to another round bottom flask and heated to evaporate the ethanol. The concentrated liquor was dried at 40-50ºC. A fine powder of pale yellow colour was collected and preserved separately to apply on the fabrics. The cotton knitted fabrics were mordanted before dyeing using copper sulphate for 30 minutes at 80˚C. After mordanting, the fabric was taken out squeezed and immersed in dye bath. Dyeing was carried out for 60 minutes at 80˚C and material to liquor ratio (MLR) maintained at 1:20 using laboratory dyeing machine. After dyeing, the fabrics were washed and squeezed. After washing the fabrics were treated with potassium di chromate with 5% concentration, 10 minutes and then dried for 24 hours. Next day, the dyed fabric samples were treated with 5% neutral soap solution and rinsed with hot and cold water and then dried.

2.3 FABRIC TESTING

After dyeing and dry relaxed knitted fabrics, the following tests were carried out for all the fabric samples. The testing of knitted fabrics was carried out in the standard atmosphere conditions of 65% RH and 27±2°C.

2.3.1 DIMENSIONAL PROPERTIES

The single jersey, 1x1 rib and interlock knitted fabrics were measured their stitch length, aerial density in gram per square meter (GSM) and fabric thickness tested at different places with the help of Shirley Thickness gauge. Spirality of these knitted fabrics was tested as per AATCC 179 test procedures.

2.3.2 FABRIC AERIAL DENSITY

The aerial density of the knitted fabrics both ring and compact spun yarn knitted fabrics were measured by grams per square metre by cutting the sample size of 10x10 cm and weighed it in the electronic balance. Then the value was multiplied by 100. The aerial densities of these knitted fabrics are given in Table 3-5.

TABLE 3. PHYSICAL PROPERTIES OF KNITTED FABRICS MADE OUT OF RING SPUN YARN

PARAMETERS	Single jersey knitted fabrics			1x1 Rib knitted fabrics			Interlock knitted fabrics		
Sample number	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
Loop length (mm)	**2.7**	**3.0**	**3.3**	**2.7**	**3.0**	**3.3**	**2.7**	**3.0**	**3.3**
Avg. count (Ne)					40s				
Avg. count (Tex)					14.76				
Course per inch (CPI)	49	44	41	45	41	36	51x2	49x2	37x2
Wales per inch (WPI)	42	41	33	39	26	39	25x2	26.x2	22x2
Tightness Factor (Tk)	14.22	12.8	11.64	14.22	12.8	11.64	14.22	12.8	11.64
Fabric thickness (mm)	0.478	0.443	0.452	0.688	0.674	0.649	0.787	0.665	0.786
Fabric weight (GSM) - calculated	132.5	112.6	108.59	175.4	132.4	112.2	264.8	235.4	224.1
Fabric weight (GSM) - measured	128.39	108.53	104.04	160.54	124.79	100.04	245.07	228.45	208.82
Air Permeability (ft^3/ft^2-min)	51.895	103.79	108.25	76.88	124.55	159.67	18.98	42.36	85.30
Fabric density (kg/m^3)	268.6	244.9	230.2	233.3	185.2	154.1	311.2	342.5	265.4
Loop shape factor	1.17	1.07	1.24	1.15	1.57	0.92	1.02	0.94	0.84

TABLE 4. PHYSICAL PROPERTIES OF KNITTED FABRICS MADE OUT OF SUSSEN ELITE SPUN YARN

PARAMETERS	Single jersey knitted fabrics			1x1 Rib knitted fabrics			Interlock knitted fabrics		
Sample number	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**
Loop length (mm)	**2.7**	**3.0**	**3.3**	**2.7**	**3.0**	**3.3**	**2.7**	**3.0**	**3.3**
Avg. count (Ne)					40s				
Avg. count (Tex)					14.76				
Course per inch (CPI)	44	44	40	42	41	38	48x2	49x2	41x2
Wales per inch (WPI)	39	35	43	40	38	34	29x2	22x2	23x2
Tightness Factor (Tk)	14.22	12.8	11.64	14.22	12.8	11.64	14.22	12.8	11.64
Fabric thickness (mm)	0.459	0.50	0.508	0.694	0.619	0.672	0.804	0.824	0.845
Fabric weight (GSM) - calculated	135.4	105.8	115.8	162.8	149.7	125.4	242.5	223.5	219.6
Fabric weight (GSM) - measured	128.39	101.25	114.25	160.54	143.86	120.74	245.07	226.65	215.47
Air Permeability (ft^3/ft^2-min)	102.09	128.89	137.31	78.82	109.25	129.74	18.986	33.12	34.25
Fabric density (kg/m^3)	279.5	202.5	224.8	231.4	232.5	179.5	306.2	275.8	254.9
Loop shape factor	1.13	1.26	0.93	1.05	1.08	1.12	0.82	1.11	0.89

TABLE 5. PHYSICAL PROPERTIES OF KNITTED FABRICS MADE OUT OF COM4 SPUN YARN

PARAMETERS	Single jersey knitted fabrics			1x1 Rib knitted fabrics			Interlock knitted fabrics		
Sample number	**S19**	**S20**	**S21**	**S22**	**S23**	**S24**	**S25**	**S26**	**S27**
Loop length (mm)	**2.7**	**3.0**	**3.3**	**2.7**	**3.0**	**3.3**	**2.7**	**3.0**	**3.3**
Avg. count (Ne)					40s				
Avg. count (Tex)					14.76				
Course per inch (CPI)	54	44	52	44	49	50	52x2	44x2	41x2
Wales per inch (WPI)	43	34	44	42	41	37	26x2	23x2	21x2
Tightness Factor (Tk)	14.22	12.8	11.64	14.22	12.8	11.64	14.22	12.8	11.64
Fabric thickness (mm)	0.474	0.479	0.465	0.655	0.693	0.812	0.815	0.786	0.831
Fabric weight (GSM) - calculated	152.2	116.8	142.2	156.3	162.7	155.4	255.6	248.6	210.7
Fabric weight (GSM) - measured	148.79	111.25	135.14	153.93	160.63	150.74	267.74	242.46	204.05
Air Permeability (ft^3/ft^2-min)	92.94	108.2	119.75	84.825	87.538	90.52	23.411	26.217	34.61
Fabric density (kg/m^3)	313.9	232.45	291.6	234.96	231.7	185.5	328.2	308.5	245.3
Loop shape factor	1.26	1.29	1.18	1.05	1.20	1.35	1.00	0.95	0.98

2.3.3 AIR PERMEABILITY

The air resistance values of the single jersey, rib knitted fabrics and interlock knitted fabrics are measured by using Kawabata Evaluation System (KES-F8-API) under automatic air permeability tester. The conversion of air resistance value of KES is converted into Frazier type tester values as per manufacturer derivation.

2.3.4 BURSTING STRENGTH

The bursting strength of the single jersey, rib and interlock knitted fabrics was tested with Bursting Strength Tester; test was carried out at ten different places per sample. The reading was noted in kg/cm^2.

2.3.5 ABRASION RESISTANCE

The abrasion resistance was tested with Martindale Abrasion Tester. Initially, the fabric samples were prepared and then weighed. Then fabrics were abraded for 50 cycles, after which the fabrics were weighed, then the differences in the two weights i.e. fabric before and after abrading were calculated and finally the percentage of abrasion loss was calculated [13].

2.3.6 PILLING

ICI pillbox tester was used to find out the pill formation on the fabrics as per ISO 12945; Part-1. For all the samples, standard 18000 revolutions were given and the fabrics were assessed for their grades. Then the fabrics were compared with the pilling standard photographs for measuring pilling grades and values were given in Table 6.

TABLE 6. EFFECTS ON PILLING

Samples	SCSL (mm)	Pilling grade		
	Actual	Ring	Sussen Elite	Compact
SJ 1	2.70	3 distrinct fuzzing	3-4 distrinct fuzzing	4 slight fuzzing
SJ 2	3.00	3 distinct fuzzing	3-4 distinct fuzzing	4 slight fuzzing
SJ 3	3.30	2-3 distinct fuzzing	3 distinct fuzzing	4 slight fuzzing
RIB 1	2.70	3-4 slight fuzzing	4 slight fuzzing	4 slight fuzzing
RIB 2	3.00	3-4 slight fuzzing	4 slight fuzzing	3-4 slight fuzzing
RIB 3	3.30	3-4 slight fuzzing	3-4 slight fuzzing	3-4 slight fuzzing
I/L 1	2.70	3-4 moderate fuzzing	4 moderate fuzzing	4 moderate fuzzing
I/L 2	3.00	3 moderate fuzzing	3-4 moderate fuzzing	3-4 moderate fuzzing
I/L 3	3.30	3 moderate fuzzing	3-4 moderate fuzzing	3-4 moderate fuzzing

Note: SJ-Single Jersey fabrics; RIB- Rib knitted fabrics; I/L- Interlock fabrics

2.3.7 FABRIC TIGHTNESS FACTOR

The tightness factor of the knitted fabrics was determined by the following equation:

$$TF = \frac{\sqrt{T}}{l} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where
TF is the fabric tightness factor,
T is the factual linear density of the yarn in Tex and *l* - the stitch length (or) loop length in cm.

The loop length was derived by unraveling 12 courses and their total length (L_T) was measured. The average loop length (or) stitch length was calculated using the following formula:

Average length (L av) = $L_T/12$
Loop length (l) = L_{av} / No. of wales… (2)

2.3.8 DIMENSIONAL STABILITY

The dimensional stability of the knitted fabric is normally derived from lengthwise shrinkage and widthwise shrinkage after laundering. The dimensional stability in terms of lengthwise shrinkage (%) and widthwise shrinkage (%) of various knitted fabrics are given in Table 7.

Aerial shrinkage was determined by measuring the sample before and after washing and the percentage areal shrinkage was calculated as:

$$S_a=S_{lw} + S_{ww} - (S_{lw}*S_{ww}) /100 \quad \text{……….(3)}$$

Where S_a is aerial shrinkage, S_{lw}- length wise linear shrinkage (%), S_{ww} is width wise linear shrinkage (%).

TABLE 7. DIMENSIONAL SHRINKAGE OF VARIOUS KNITTED FABRICS

Knit structure	Single jersey				Rib structure				Interlock structure		
	Ring	Sussen Elite	Com4		Ring	Sussen Elite	Com4		Ring	Sussen Elite	Com4
Length wise shrinkage,%											
2.7mm	(-) 4.4	(-)2.4	(-)1.2		(+)1.2	(+)1.2	(-)2.8		(-)2.0	(+)0.8	(-)0.8
3.0mm	(-) 1.6	(-)1.2	(-)1.2		(+)1.6	(+)2.8	(-)1.6		(+)2.8	(-)1.2	(-)4.4
3.3mm	(+)2.0	(-)2.8	(-)1.2		(+)6.0	(+)6.4	(-)2.0		(+)2.0	(-)2.0	(-)1.2
Widthwise shrinkage,%											
2.7mm	(-)12.8	(-)6.4	(-)2.8		(-)12.4	(-)11.2	(-)10.0		(-)2.0	(-)2.0	(-)2.0
3.0mm	(-)5.2	(-)5.6	(-)6.0		(-)13.6	(-)14.4	(-)4.4		(-)9.2	(-)4.4	(-)2.4
3.3mm	(-)8.4	(-)8.4	(-)4.0		(-)19.6	(-)24.4	(-)13.2		(-)9.2	(-)3.2	(-)7.2

3. RESULTS AND DISCUSSION

3.1 EFFECT OF PILLING

The pilling characteristics of the single jersey, rib and interlock knitted fabric made out of ring and compact spun yarn such as Sussen Elite and Com4 spun yarn with different stitch loop length of 2.7mm, 3.0mm and 3.3mm respectively have been studied and their pilling grades are given in Table 6. It is noticed that Com4 and Sussen Elite compact spun yarn knitted fabrics have shown 3-4 higher pilling grades which have higher pill resistance and less fuzzing when compared to ring spun yarn, it may be because of better integration of fibres into core yarn structure in compact yarn. The pilling resistance of the knitted fabrics have been observed higher in case of 2.7mm stitch length when compared to 3.3mm loop length, it is because of the higher fibre content and higher probability to form fuzzing on the surface of the fabric. The pilling resistance of the single jersey knitted fabric followed the same trend completely. Ring, Sussen Elite and Com4 spun yarns have showed lower than the other structures such as rib and interlock structure; it may be because of higher abrasion resistance and better yarn packing of fabrics.

3.2 WEIGHT LOSS (%) IN ABRASION

The weight loss (%) in abrasion of the single jersey, rib and interlock knitted fabric made out of ring and compact spun yarns have been studied and showed in Figure 2 and 3. From Figure 2, the abrasion losses of the single jersey knitted fabrics have noticed higher than rib and interlock knitted fabrics. The higher weight loss (%) in abrasion was noticed in case of ring spun yarn compared to compact spun yarn such as Sussen Elite and Com4. It was also noticed that the loss of the knitted fabrics increases when the stitch length decreases. It is because of the higher fabric density and fibre content in lower stitch length knitted fabrics.

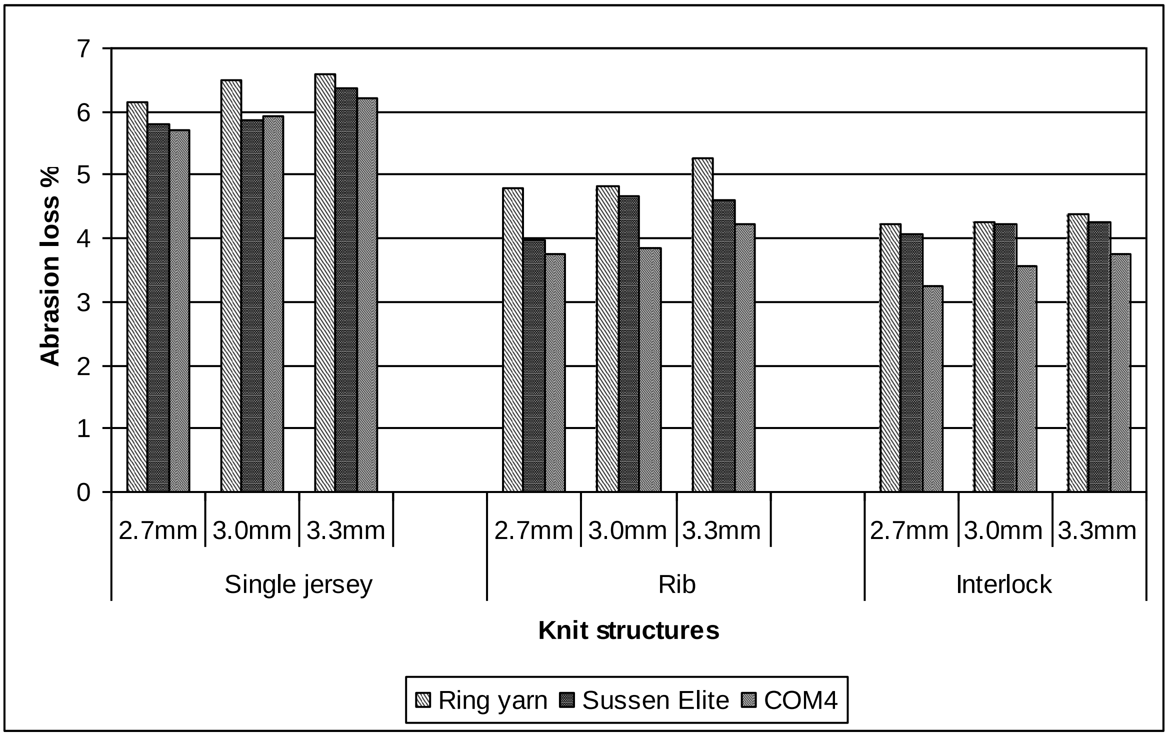

FIGURE 2. ABRASION LOSS % OF VARIOUS KNITTED STRUCTURES MADE OUT OF DIFFERENT LOOP LENGTH

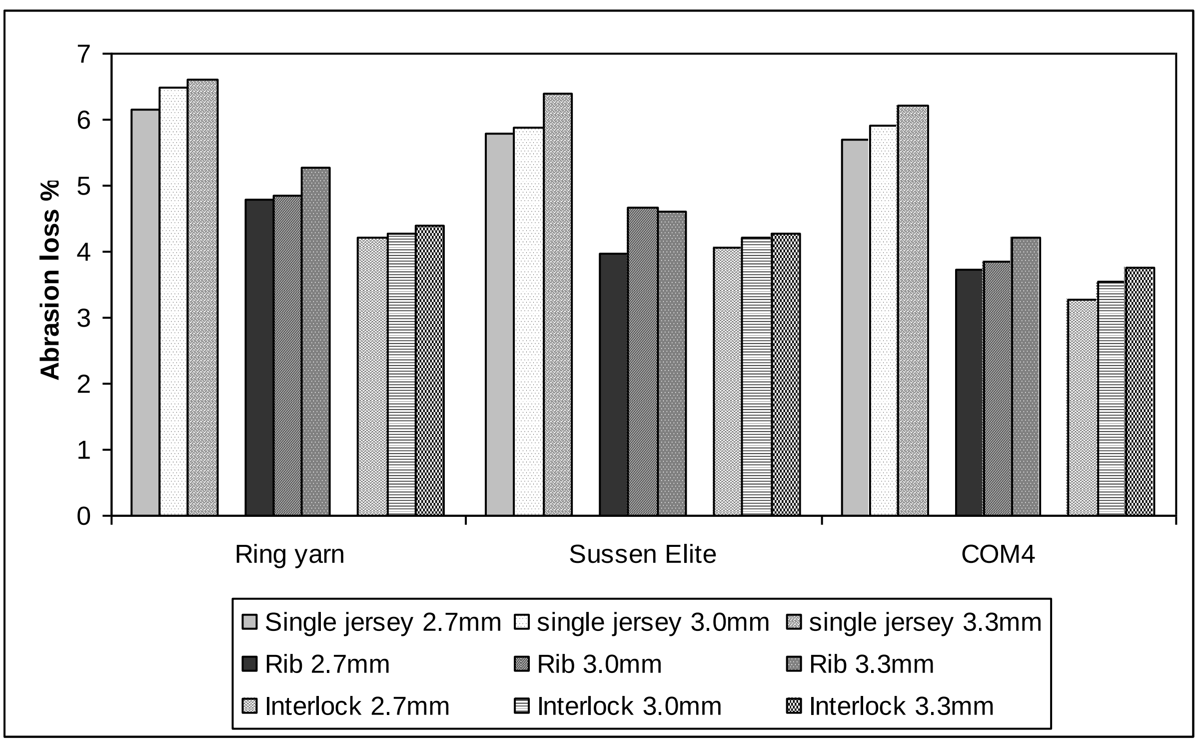

FIGURE 3. ABRASION LOSS % OF RING SPUN, SUSSEN ELITE AND COM4 SPUN YARNS

3.3 SPIRALITY

Spirality (%) of the single jersey, rib and interlock knitted fabrics made out of ring and compact spun yarns have been studied and shown in Figure 4 and 5. From Figure 4, the spirality of the single jersey knitted fabrics made out of the ring and compact spun yarns were higher than the rib and interlock knitted fabrics. It is observed that the percentage of spirality increases when the stitch length of the knitted fabric increases and it is because of the lower tightness factor and the lower fabric areal density of the knitted fabrics. It is also found same trend in all the knitted fabrics made out of ring and compact spun yarns. The spirality (%) of the Com4 and Sussen Elite spun yarns had lower values when compared to ring spun yarn knitted fabrics. It is because of the lower twist level in compact yarns and higher yarn packing factor due to the compaction of hair fibre into the core structure of the yarn.

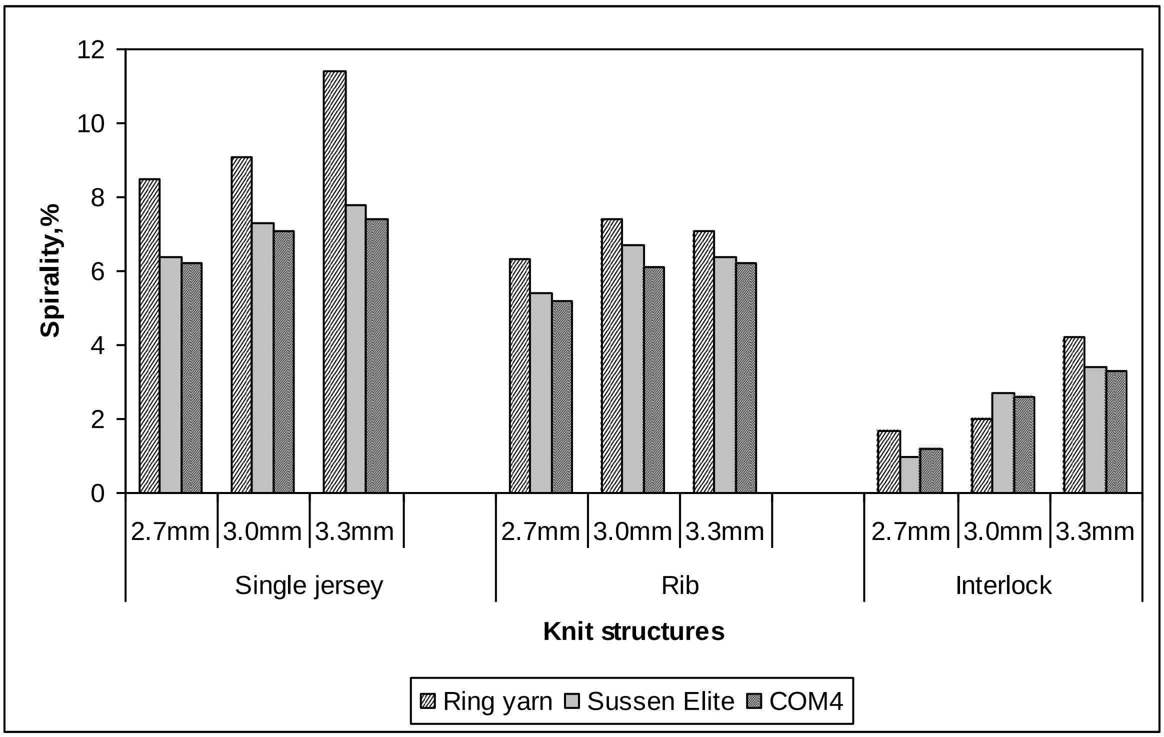

FIGURE 4. SPIRALITY % OF VARIOUS KNITTED STRUCTURES MADE OUT OF DIFFERENT LOOP LENGTH

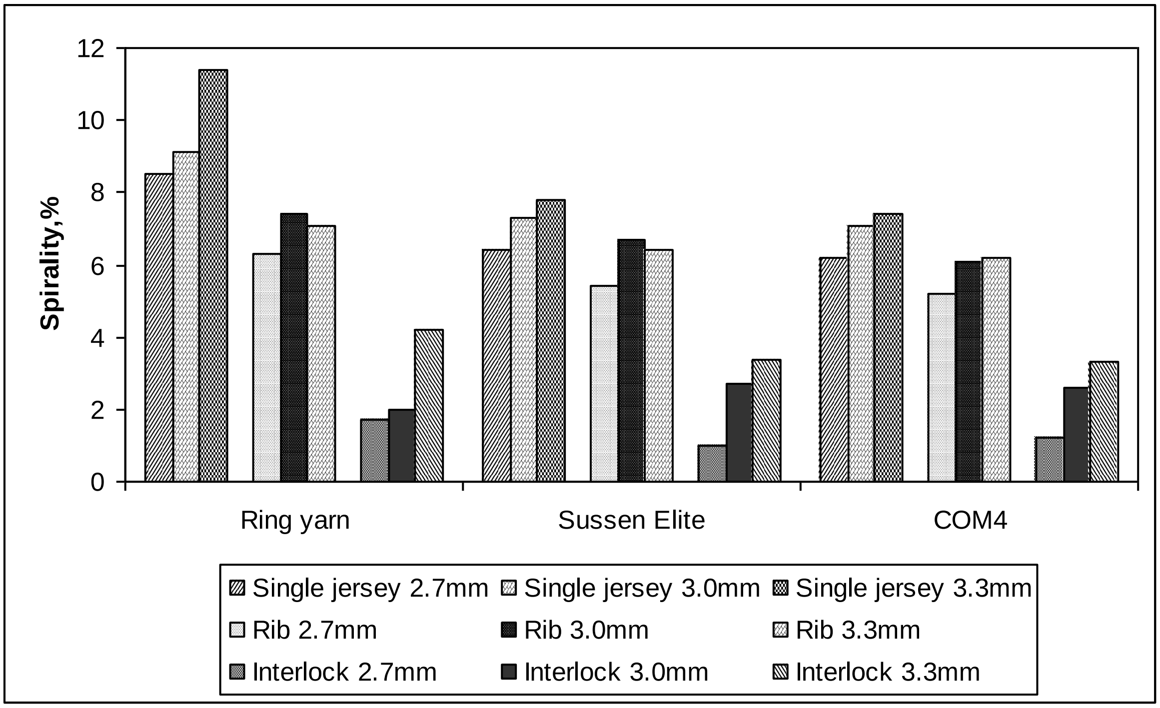

FIGURE 5. SPIRALITY % OF RING SPUN, SUSSEN ELITE AND COM4 SPUN YARNS

3.4 WICKABILITY

The wicking characteristics of single jersey rib and interlock knitted fabrics made out of ring, Sussen Elite and Com4 spun yarns with various loop length of 2.7mm, 3.0mm and 3.3mm have been studied. From Figures 6 to 9 represent the wicking characteristics of ring, Sussen and Com4 spun yarn single jersey, 1x1 rib and 1x1 interlock knitted fabrics with 2.7mm loop length respectively. It is noticed that the compact spun yarn both Sussen Elite and Com4 spun yarn knitted fabrics have higher wicking height compared to the ring spun yarn and it is because of uniform packing of fibres and lower yarn twist in compact yarn structure and uniform yarn surface which imparts the surface tension to rise the wicking. These test result findings are correlated with Subrata Das et al [12] and Kane C D et al [13] in case of wicking behaviour of compact and ring spun yarns.

The wicking characteristics of these yarns made out of single jersey knitted fabric were noticed higher wicking height in all the loop length of 2.7mm, 3.0mm and 3.3mm respectively when compared to rib and interlock knitted structures, due to the higher fabric density and resistance to water rise. Because of higher absorbency nature in transverse and longitudinal direction, it resists the wicking of the water rise in the rib and interlock fabric structures. From Figure 6 represents the relationship between the wicking characteristics of single jersey knitted fabric made out of different stitch length such as 2.7mm, 3.0mm and 3.3mm. It was noticed that the wicking height of single jersey knitted fabrics made out of 3.3mm loop length has higher when compared to the 2.7mm and 3.0mm stitch length single jersey knitted fabrics. It is because of the lower absorption of water and it allows rising of water and increases the surface tension to the fabric when compared to lower stitch length knitted fabrics. Same trend was observed in all the knitted fabrics made out of Ring, Sussen Elite and Com4 spun yarn single jersey, rib and interlock knitted structures.

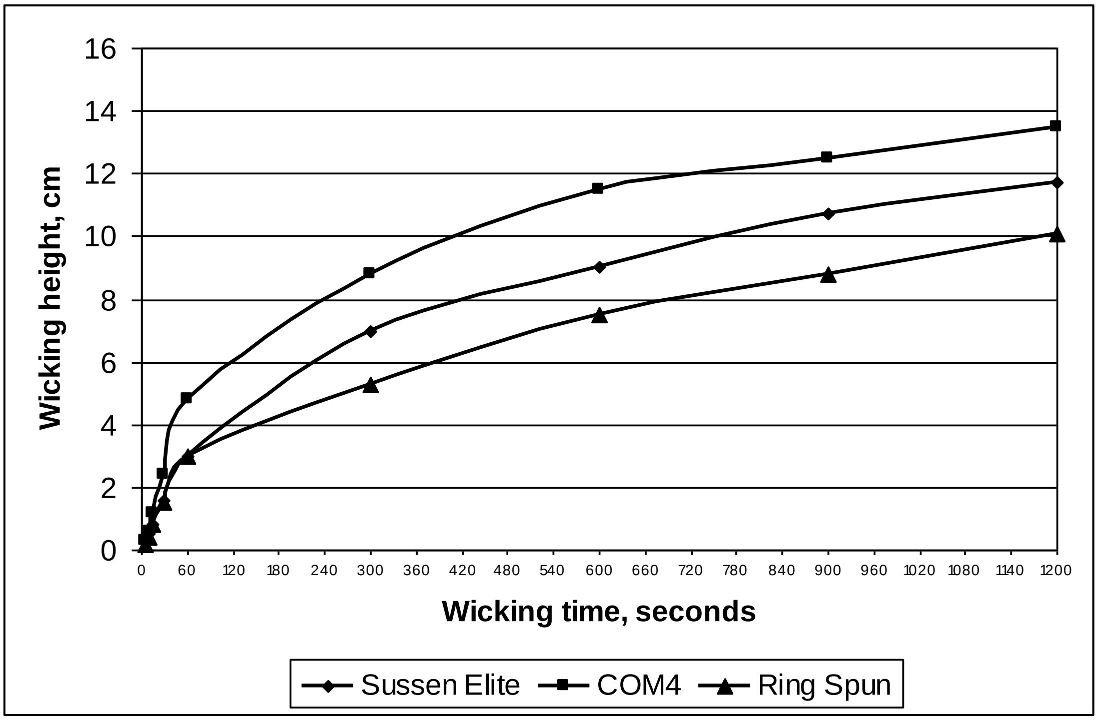

FIGURE 6. WICKING BEHAVIOUR OF RING, SUSSEN ELITE AND COM4 SPUN YARN SINGLE JERSEY KNITTED FABRICS AT 2.7MM LOOP LENGTH

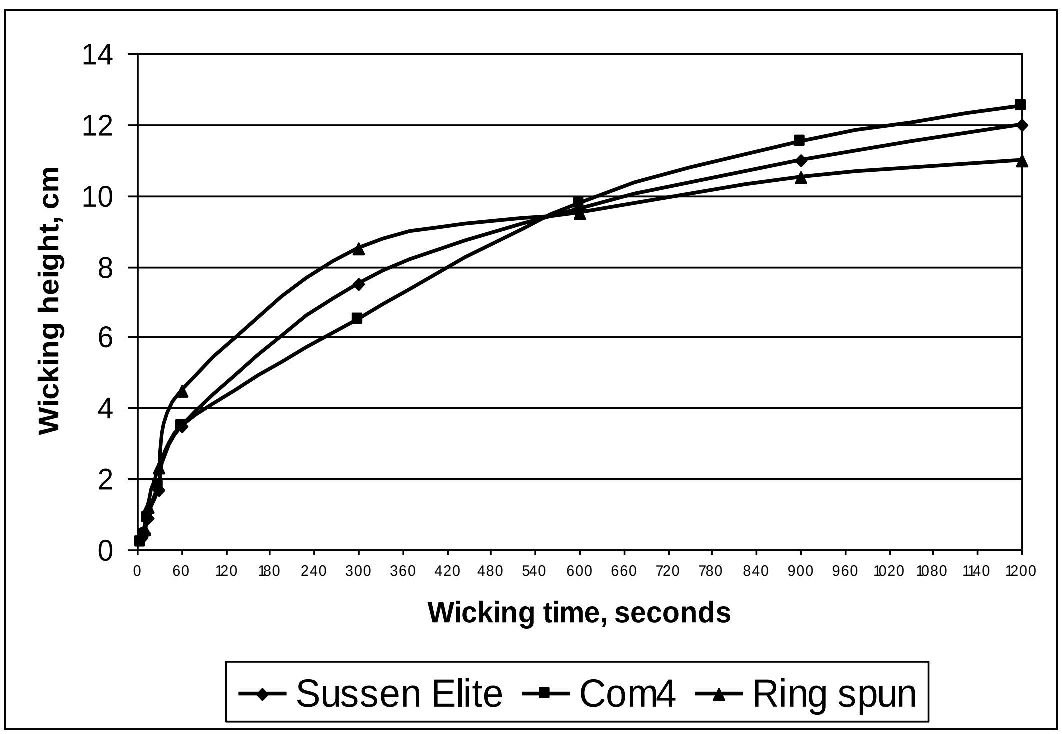

FIGURE 7. WICKING BEHAVIOUR OF RING, SUSSEN ELITE AND COM4 SPUN YARN 1X1 RIB KNITTED FABRICS AT 2.7MM LOOP LENGTH

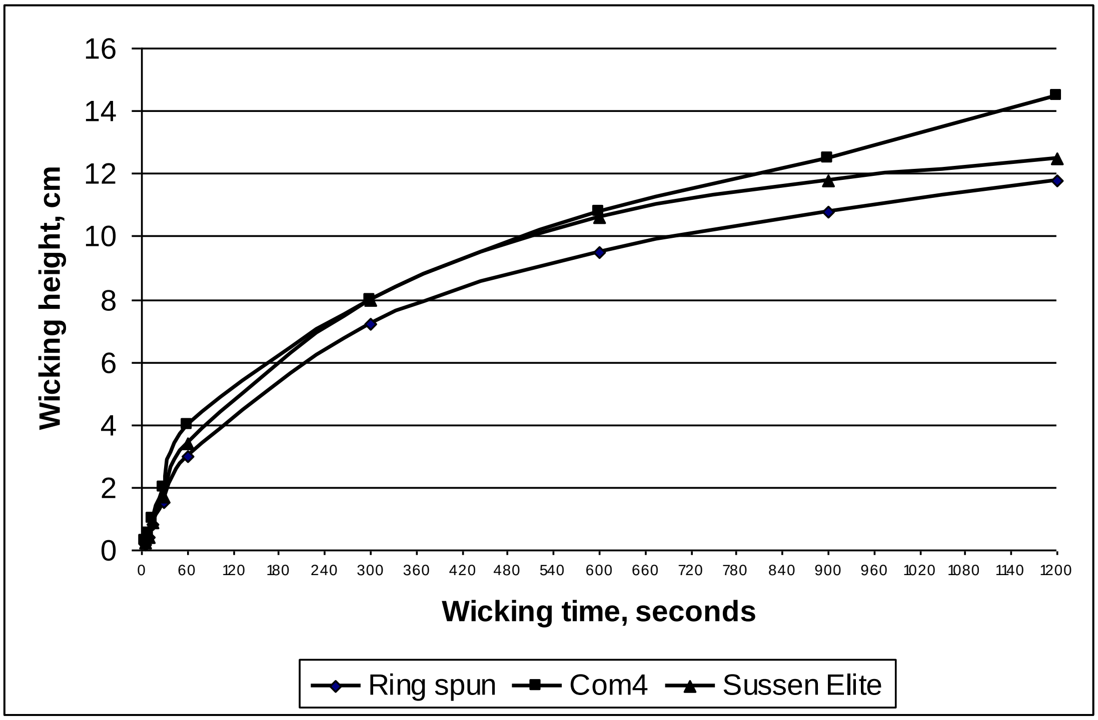

FIGURE 8. WICKING BEHAVIOUR OF RING, SUSSEN ELITE AND COM4 SPUN YARN 1X1 INTERLOCK KNITTED FABRICS AT 2.7MM LOOP LENGTH

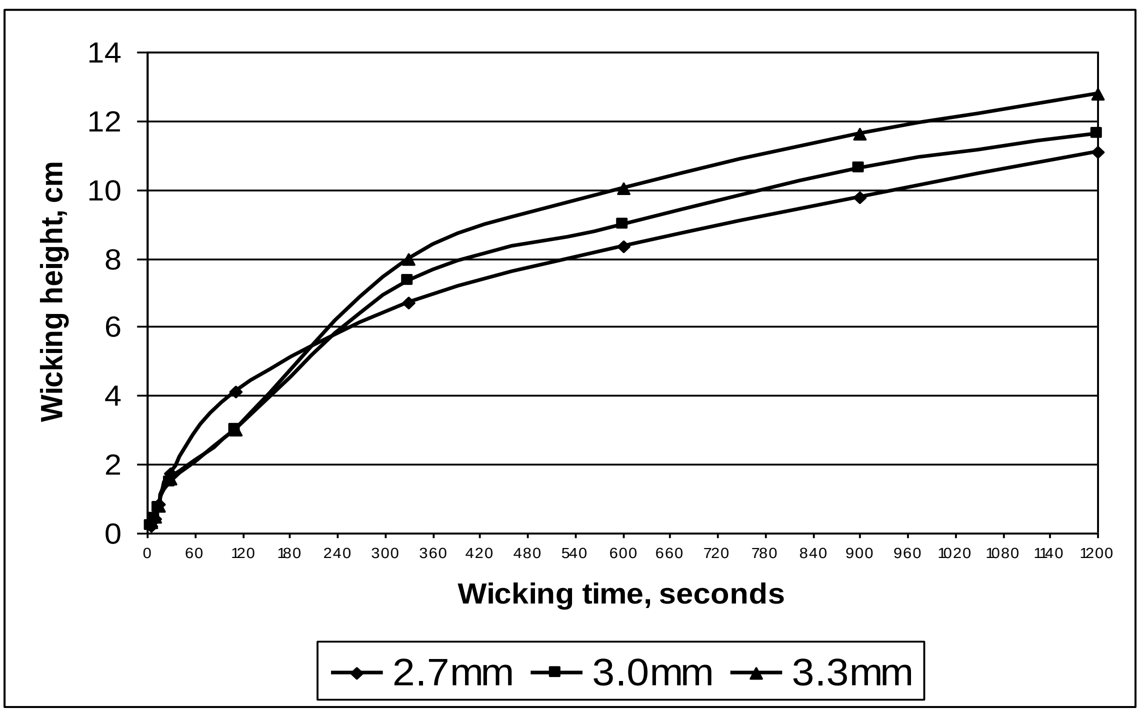

FIGURE 9. WICKING BEHAVIOUR OF COM4 SPUN YARN SINGLE JERSEY KNITTED FABRICS MADE OUT OF DIFFERENT LOOP LENGTH

3.5 BURSTING STRENGTH

The bursting characteristics of single jersey rib and interlock knitted fabrics made out of Ring, Sussen Elite and Com4 spun yarns with various stitch length of 2.7mm, 3.0mm and 3.3mm have been studied. Figure 10 represents the relationship between the bursting characteristics of single jersey, rib and interlock knitted fabrics made out of different loop length such as 2.7mm, 3.0mm and 3.3mm respectively. The bursting characteristics of single jersey knitted fabrics were noticed lower values when compared to rib and interlock fabrics; it is because of the structure and lower tightness factor and fabric aerial density. Also significant differences were found in bursting strength of same knit structure with different loop length and it is because of higher fabric density and tightness factor in lower loop length knitted fabrics. When the stitch length of the knitted fabric increases, the bursting strength decreases for all the three knitted structures. This is due to the stitch length which was less; number of loops per square inch was more. Therefore, the resistance towards the force was more in case of lower stitch length fabrics. The knitted fabric from compact yarns was shown higher bursting strength due to higher yarn breaking strength; it is due to good integration of fibres and uniform fibre arrangement which led to better fibre strength exploitation than the fabrics from ring yarn for all the derivatives.

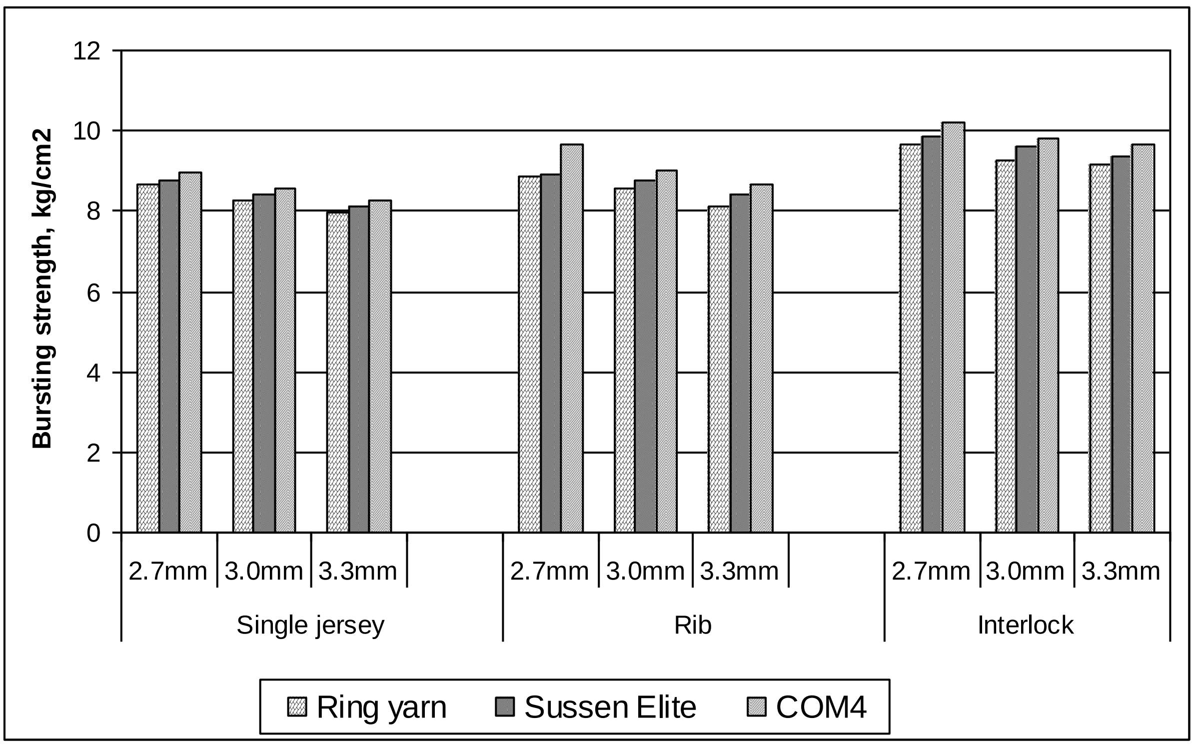

FIGURE 10. BURSTING CHARACTERISTICS OF VARIOUS KNITTED STRUCTURES MADE OUT OF DIFFERENT LOOP LENGTH

3.6 ANOVA MULTIVARIABLE DATA ANALYSIS

The significant difference of the various physical characteristics such as abrasion loss, air permeability, dimensional shrinkage and spirality of various knitted fabrics were noticed between knit structures, stitch length and yarn types are given in Table 8.

Hypothesis 1: Tightness factor and loop shape factor Vs Dimensional shrinkage

The dimensional shrinkage of the knitted fabric made of single jersey structure was noticed higher aerial shrinkage compared to the rib and interlock structured fabrics. It is due to the stitch length and tightness factor. If the stitch length is larger, number of loops in the length and widthwise direction are lesser then the fabric stitch density (courses/cm x wales/cm) becomes lower. It causes variation in loop shape factor and leads to shrinkage in length wise or widthwise direction in the knitted fabrics. It is also confirmed with ANOVA multivariable analysis that $F_{(2,8)}$ 20.99>6.9942 (F_{actua}l>$F_{critica}$l) at 95% confidence level, significant difference in dimensional shrinkage of all the knit structures and yarn types in various stitch length is noticed. Further, the stitch length of the knitted fabrics is directly proportional to the dimensional shrinkage of the fabric is identified.

Hypothesis 2: Tightness factor and fabric thickness Vs Air permeability

The fabric transport property, which is more sensitive to fabric structure, is air permeability, defined as the volume flow rate per unit area of a fabric when there is a specified differential pressure across two faces of the fabric. The air permeability of the single jersey knitted fabrics was noticed higher than rib and interlock knitted fabrics. It is because of the lower tightness factor and fabric thickness. Besides, the compact spun yarn single jersey knitted fabrics had lower air permeability than the ring spun yarn knitted fabrics, due to the better integration of the fibres and higher yarn packing density of the compact yarns was identified. It is also confirmed with ANOVA multivariable analysis that $F_{(2,8)}$ 8.881>6.9942 (F_{actua}l>$F_{critica}$l) at 95% confidence level, significant difference in tightness factor and air permeability in all the knitted fabrics. Fabric thickness is also an influential factor for air permeability of the knitted fabrics. Hence the single jersey knitted fabric had higher air permeability compared to rib and interlock structures.

TABLE 8. ANOVA MULTIVARIABLE DATA ANALYSIS

Variance analysis	Degree of freedom (df)	Sum of Square value (SS)	Mean Square value (MS)	F_{actual}	$F_{critical}$	P_{value}
Abrasion loss						
Between knit structures	2	7.172	3.586178	59.65915	6.944	0.001052
Between stitch length	2	13.975	6.9877	19.9019	6.994	0.008339
Between yarn types	2	5.068	2.5344	7.2183	6.944	0.04707
Air permeability						
Between knit structures	2	10136	5068.066	156.89	6.944	0.000158
Between stitch length	2	2580.895	1290.448	12.878	6.994	0.01807
Between yarn types	2	1779.921	889.9606	8.8813	6.944	0.0337
Dimensional shrinkage						
Between knit structures	2	66.427	33.213	12.92	6.944	0.1915
Between stitch length	2	31.093	15.546	20.990	6.994	0.007
Between yarn types	2	7.144	3.572	4.823	6.944	0.0859
Spirality						
Between knit structures	2	53.608	26.804	109.65	6.944	0.000321
Between stitch length	2	13.975	6.987	19.90	6.994	0.008339
Between yarn types	2	5.068	2.5344	7.215	6.944	0.0471

Hypothesis 3: Dimensional stability

From Table 7, the width wise shrinkage of the single jersey, rib and interlock knitted fabrics made out of ring spun yarns with various stitch length of 2.7mm, 3.0mm and 3.3mm were higher compared to the compact spun yarn knitted fabrics of Sussen Elite and Com4 yarns. It is because of the loop shape factor which usually becomes rounder in shape caused shrinkage in the wale direction, especially when the fabric has previously dried under tension. It causes course density after laundering increases to 7.8% for single jersey, around 4% for interlock and around 6.5% for rib structures respectively. Stitch density also increases to 4-7.2% for enzymatic scoured and 13-16.5% for bleached single jersey fabrics. The lengthwise shrinkage of the rib and interlock knitted fabrics made out of ring and compact spun yarns were noticed minimum and positive values (+) were identified. It represents the widthwise shrinkage of the fabric reflects contraction because of loop shape factor. To release the stresses imposed by bending twisted yarn into loops, the loops themselves tend to twist out of the plane of the fabric. It causes the spirality of the knitted fabrics. The compact spun yarn knitted fabrics in all the knit structures were noticed lower dimensional shrinkage; aerial shrinkage of the knitted fabrics were mainly depend on the stitch length, loop shape factor and tightness factor of the fabrics.

CONCLUSIONS

The physical characteristics such as weight loss (%) in abrasion, pilling resistance, air permeability, fabric tightness factor, loop shape factor, wickability, bursting strength, spirality and dimensional stability of eco-friendly processed ring, Sussen Elite and Com4 spun yarn knitted fabrics have been studied with various structures and stitch length. The compact spun yarn knitted fabrics made out of Sussen Elite and Com4 spinning systems have higher bursting strength, pilling resistance, better dimensional stability, wickability and spirality when compared to ring spun yarn knitted fabrics for all the knit structures such as single jersey, rib and interlock. The loop shape factor for the compact spun yarn knitted fabrics was noticed better after laundering when it was compared to ring spun yarn fabrics because of the better integration of the fibres and lower dimensional shrinkage in length and widthwise directions. The significant differences were also noticed in air permeability and spirality of all the knitted fabrics with various stitch length and knit structures. Hence, the higher stitch length (3.3 mm) of knitted fabrics was noticed lower fabric tightness factor and higher spirality which caused higher dimensional shrinkage. It is also confirmed with ANOVA multivariable analysis which shown $F_{(2,8)}$ 19.90>6.9942 ($F_{actua}l$>$F_{critica}l$) at 95% confidence level, noticed significant difference in dimensional shrinkage of knitted fabrics between stitch length of 2.7mm and 3.3mm was identified. Hence the compact spun yarn weft knitted fabrics having better physical characteristics compared to ring yarn weft knitted fabrics which will more suitable for manufacturing of knitwear garments. This research work will pave the way to scientist / researchers / designers in the field of knitwear fabric and garment manufacturing through eco-friendly processes.

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